



**Faculty of Electronic and Computer Engineering**

**ENHANCED DESIGN OF ELECTRONICALLY RECONFIGURABLE  
INTEGRATED MICROWAVE FILTER AND ANTENNA FOR  
WIRELESS COMMUNICATION SYSTEMS**

**Sam Weng Yik**

**Doctor of Philosophy**

**2018**

**ENHANCED DESIGN OF ELECTRONICALLY RECONFIGURABLE  
INTEGRATED MICROWAVE FILTER AND ANTENNA FOR WIRELESS  
COMMUNICATION SYSTEMS**

**SAM WENG YIK**

**A thesis submitted  
in fulfillment of the requirements for the degree of Doctor of Philosophy**

**Faculty of Electronic and Computer Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2018**

## DECLARATION

I declare that this thesis entitled “Enhanced Design of Electronically Reconfigurable Integrated Microwave Filter and Antenna for Wireless Communication Systems” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : .....

Date : .....

## **APPROVAL**

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature : .....

Supervisor Name : .....

Date : .....

## **DEDICATION**

To my beloved mother and father

## ABSTRACT

The reconfigurable integrated filter and antenna is one of the major interest for researchers due to the potential significant advantages compare to the typical standard integrated structure. The growth in reconfigurable integrating technology is not limited to a single tunable parameter such as operating frequency, bandwidth and attenuation but it can be combination parameters depending on the applications. There are many techniques have been developed to achieve adaptable reconfigurable integrated filter and antenna but majorities of the reconfigurable designs are focused on a single element either on an antenna or the filter. Thus, it limits the tunable range and flexibility response of the reconfigurable design will be a challenging task. On the other hand, developing a Ultra-Wideband (UWB) antenna is one of the crucial components for UWB communications systems and has been widely studied for many years. Moreover, the reconfigurable UWB designs can be developed the desired filtering antenna which can reject unwanted signal interferences. However, most of these techniques produce excessive band rejection, which leads to reject desired frequencies, thus producing a narrowband notch characteristics is a challenging issue. Therefore, the aim of this research is to design novel structure of reconfigurable integrated technique of planar structure which promises a new potential functionality of the microwave devices. Two designs approach were introduced which is reconfigurable SIW filter and antenna and reconfigurable dual band-notched UWB antenna using FR-4 substrate and Roger Duroid RO4350B with dielectric constant of 4.6 and 3.48 respectively. To realize the concept, reconfigurable SIW filter and reconfigurable patch antenna have been combined using the multilayer technique into a single structure while UWB antenna and reconfigurable notch filter were combined on the same planar. To validate the design technique, the equivalent circuit model of the tunable varactor diode network is presented to study the tunability mechanism. Two commercial software programs that have been used in the design and development of two main designs namely Advanced Design System (ADS) software and CST Studio Suite software. All designs were simulated, manufactured and measured. Reconfigurable integrated SIW filter and antenna provide a good attenuation tuning range about 15.5 dB with improvement up to 55 % and only shifts 1 MHz from the origin centre frequency while reconfigurable UWB antenna with band-notched provide a good range up to 210 MHz. This design has smaller compact size of 37.6 mm x 28.0 mm with bandwidth for peak notch of 224.76 MHz and 89.90 MHz for both notches. The experimental results show a good agreement with the simulated results. The benefits of the reconfigurable integrated design are potentially miniaturizing overall structure, good tuning capability, easy to fabricate and cost effective. The outcomes of the proposed reconfigurable integrated design may facilitate improvements in an integrated technique with a good tuning capability for wireless communication systems.

## ABSTRAK

Konfigurasi semula integrasi penapis dan antenna adalah salah satu kepentingan utama penyelidik kerana kelebihan yang signifikan berbanding struktur integrasi biasa. Pertumbuhan konfigurasi semula integrasi teknologi tidak terhad kepada parameter tunggal seperti frekuensi operasi, lebar jalur dan pelemahan tetapi ia boleh dijadikan parameter gabungan bergantung kepada aplikasinya. Banyak teknik telah dilakukan mengenai konfigurasi semula integrasi penapis dan antenna, tetapi majoriti reka bentuk tertumpu pada satu elemen sama ada pada antenna atau penapis. Malahan, ia mengehadkan julat boleh tala dan fleksibiliti penapis dan antenna tersebut serta menjadi tugas yang mencabar. Sebaliknya, antenna UWB adalah salah satu komponen yang penting dalam sistem komunikasi UWB dan telah dikaji selama bertahun-tahun. Lebih-lebih lagi, konfigurasi semula antenna UWB dengan jalur takuk boleh dibangunkan untuk membentuk satu antenna penapisan di mana boleh menapis gangguan isyarat yang tidak diingini. Tambahan pula, kebanyakan teknik ini menghasilkan tolak jalur yang berlebihan dan menapis frekuensi yang diingini, oleh itu untuk menghasilkan jalur sempit merupakan isu yang mencabar. Oleh itu, tujuan penyelidikan ini adalah untuk mereka bentuk dan membangunkan satah struktur konfigurasi semula integrasi penapis dan antenna baru yang berfungsi dalam peranti mikro gelombang. Dua pendekatan reka bentuk diperkenalkan iaitu konfigurasi semula integrasi penapis pandu gelombang berinteraksi substrat (SIW) dan antenna tampalan dan konfigurasi semula antenna UWB dengan jalur takuk dengan menggunakan substrat FR-4 dan Roger Duroid RO4350B dengan pemalar dielektrik 4.6 dan 3.48. Untuk merealisasikan konsep ini, konfigurasi semula penapis SIW dan konfigurasi semula antenna tampalan boleh digabungkan menggunakan teknik berbilang lapis ke dalam struktur tunggal manakala antenna UWB dan konfigurasi semula jalur takuk digabungkan dalam satah yang sama. Untuk mengesahkan teknik reka bentuk, model litar setaraf rangkaian diod varactor boleh dikaji melalui mekanisme julat boleh tala. Dua perisian komersil yang digunakan dalam reka bentuk dan pembangunan iaitu Advanced Design System (ADS) dan CST Studio Suite. Konfigurasi semula integrasi penapis SIW dan antenna menyediakan penalaan pelemahan yang baik iaitu 15.5 dB dengan penambahbaikan sebanyak 55 % dan hanya beralih sebanyak 1 MHz dari frekuensi asal manakala pentatahrajahan semula antenna UWB dengan jalur takuk memberikan penalaan frekuensi yang baik sehingga 210 MHz. Reka bentuk ini mempunyai saiz yang kecil iaitu 37.6 mm x 28.0 mm dengan jalur lebar untuk notch puncak iaitu 224.76 MHz dan 89.90 MHz untuk kedua-dua notch. Semua reka bentuk disimulasikan, dihasilkan dan diukur. Keputusan eksperimen menunjukkan persetujuan yang baik dengan hasil simulasi. Manfaat konfigurasi semula integrasi reka bentuk berpotensi untuk membentuk struktur yang kecil, keupayaan penalaan yang baik, mudah dan kos efektif. Hasil daripada reka bentuk konfigurasi semula integrasi yang dicadangkan boleh menaik taraf peningkatan dalam teknik integrasi dengan keupayaan julat boleh tala yang baik untuk sistem komunikasi tanpa wayar.

## ACKNOWLEDGEMENTS

I would like to express my appreciation to my main supervisor, Associate Professor Dr. Zahriladha bin Zakaria who had guided me throughout my journey in writing this thesis and for his advices that had greatly improved my knowledge on the microwave field. I am also very thankful to my co-supervisor, Professor Abdul Rani bin Othman for his guidance, advice and motivation. Without their continued moral support and concern, this thesis would not have been presented here.

My fellow postgraduate students should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Importantly, my study would not be possible without my sponsors. I would like to acknowledge the Ministry of Higher Education (MOHE), MyPhD MyBrain15 and Universiti Teknikal Malaysia Melaka (UTeM) for the scholarships and the research grants. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members. Finally, I would like to extend my gratitude to everyone who have been directly and indirectly involved in the successful completion of this thesis.



## TABLE OF CONTENTS

	PAGE
<b>DECLARATION</b>	
<b>APPROVAL</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	i
<b>ABSTRAK</b>	ii
<b>ACKNOWLEDGEMENTS</b>	iii
<b>TABLE OF CONTENTS</b>	iv
<b>LIST OF TABLES</b>	viii
<b>LIST OF FIGURES</b>	xi
<b>LIST OF APPENDICES</b>	xxvii
<b>LIST OF ABBREVIATIONS</b>	xxvii
<b>LIST OF SYMBOLS</b>	xxx
<b>LIST OF PUBLICATIONS</b>	xxxii
 <b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Background	1
1.2 Problem Statement	5
1.3 Objectives	8
1.4 Scope of Research	8
1.5 Original Contribution Presented In This Thesis	9
1.6 Thesis Organization	10
 <b>2. LITERATURE REVIEW</b>	<b>13</b>
2.1 Introduction	13
2.1.1 Effects of Losses on Bandpass Filter	14
2.1.2 Introduction to Reconfigurable Element	17
2.2 Resonant Circuit Theory	20
2.2.1 Single-Mode Filter (Passive)	20
2.2.2 Single-Mode Filter (Active)	22
2.2.3 Bandstop Filter (Passive)	22
2.2.4 Bandstop Filter (Active)	23
2.2.5 Single-Mode Antenna (Passive)	24
2.2.6 Single-Mode Antenna (Active)	26
2.2.7 Integrated Filter and Antenna (Passive)	26
2.2.8 Integrated Filter and Antenna (Active)	28
2.3 Overview of Microwave Filter	28
2.3.1 Substrate Integrated Waveguide (SIW) Filter	29
2.3.2 Recent Development of SIW Filter	30
2.3.3 Substrate Integrated Waveguide (SIW)	35
2.4 Microstrip Patch Antenna	36
2.4.1 Overview of Microstrip Patch Antenna	37
2.4.2 Review of Microstrip Patch Antenna	38
2.5 Integrated SIW Filter and Microstrip Patch Antenna	41
2.5.1 Review of Integrated Microwave Filter and Antenna	42

2.6	Review of Reconfigurable Design	48
2.6.1	Reconfigurable Filter	48
2.6.2	Reconfigurable Microstrip Patch Antenna	57
2.6.3	Reconfigurable Integrated Filter and Antenna	65
2.7	Ultra-wideband (UWB)	70
2.7.1	Review of Ultra-Wideband Antenna with Notched Band Response	71
2.7.2	Review of Reconfigurable Ultra-Wideband Antenna with Notched Band Response	83
2.8	Summary	91
<b>3.</b>	<b>METHODOLOGY</b>	<b>92</b>
3.1	Introduction	92
3.2	Flow Chart	93
3.3	Design of Microwave Filter	97
3.3.1	Substrate Integrated Waveguide (SIW) Design	97
3.3.2	Bandstop Filter Design Rules	101
3.4	Design of Microstrip Patch Antenna	103
3.4.1	Rectangular Microstrip Patch Antenna Design	103
3.4.2	Transmission Line Model	103
3.4.3	Circular UWB Microstrip Patch Antenna Design	109
3.5	Design of Integrated Filter and Antenna	111
3.6	Design of UWB Antenna with Band-Notched	112
3.7	Design of Reconfigurable Integrated Design	113
3.7.1	Biasing Circuit	113
3.7.2	Reconfigurable SIW Filter and Antenna	114
3.7.3	Reconfigurable UWB Antenna with Band-Notched	116
3.8	Simulation Tools	117
3.9	Fabrication of Proposed Design	118
3.10	Measurement Setup	120
3.11	Summary	121
<b>4.</b>	<b>RESULT AND DISCUSSION: RECONFIGURABLE INTEGRATED FILTER AND ANTENNA</b>	<b>122</b>
4.1	Introduction	122
4.2	Single-Mode Bandpass Filter	123
4.2.1	Bandpass Filter Based on Circuit Theory	123
4.2.2	Single-Mode Substrate Integrated Waveguide (SIW) Bandpass Filter	125
4.2.3	Manufacturing and Measurement Results	130
4.3	Single-Mode Microstrip Patch Antenna	132
4.3.1	Antenna Based on Circuit Theory	132
4.3.2	Rectangular Microstrip Patch Antenna	133
4.3.3	Manufacturing and Measurement Results	139
4.4	Single-Mode Integrated SIW Filter and Patch Antenna	142
4.4.1	Integrated Filter and Antenna Based on Circuit Theory	142
4.4.2	Integrated SIW Filter and Patch Antenna (Multilayer)	143
4.4.3	Manufacturing and Measurement Results	150

4.5	Single-Mode Reconfigurable Bandpass Filter	154
4.5.1	Reconfigurable Bandpass Filter Based on Circuit Theory	154
4.5.2	Reconfigurable Substrate Integrated Waveguide (SIW) Bandpass Filter	155
4.5.3	Manufacturing and Measurement Results	161
4.6	Single-Mode Reconfigurable Antenna	164
4.6.1	Reconfigurable Antenna Based on Circuit Theory	164
4.6.2	Reconfigurable Microstrip Patch Antenna	164
4.6.3	Manufacturing and Measurement Results	170
4.7	Single-Mode Reconfigurable Integrated Filter and Antenna	174
4.7.1	Reconfigurable Integrated Filter and Antenna Based on Circuit Theory	174
4.7.2	Reconfigurable Integrated SIW Filter and Antenna Based on Multilayer Approach	176
4.7.3	Manufacturing and Measurement Results	190
4.8	Comparison of Results	198
4.9	UWB Antenna	199
4.9.1	UWB Antenna Based on Circuit Theory	199
4.9.2	UWB Microstrip Patch Antenna	201
4.9.3	Manufacturing and Measurement Results	206
4.10	Notch Filter	209
4.10.1	Notch Filter Based on Circuit Theory	209
4.10.2	Notch Filter Based on L-Shaped Resonator	210
4.10.3	Manufacturing and Measurement Results	215
4.11	Reconfigurable Notch Filter	217
4.11.1	Reconfigurable Notch Filter Based on Circuit Theory by Using NXP BB202	217
4.11.2	Reconfigurable L-Shaped Notch Filter by Using NXP BB202	219
4.11.3	Manufacturing and Measurement Results	225
4.12	UWB Antenna with Band-Notched	228
4.12.1	UWB antenna with Band-Notched Based on Circuit Theory	228
4.12.2	UWB antenna with Band Notched (Passive)	229
4.12.3	Manufacturing and Measurement Results	235
4.13	Reconfigurable UWB Antenna with Band-Notched	238
4.13.1	Reconfigurable UWB Antenna with Notch Filter Using NXP BB202	238
4.13.2	Manufacturing and Measurement Results	242
4.14	Additional Simulation Analysis for Reconfigurable Notch Filter and Reconfigurable UWB Antenna with Band-Notched	244
4.14.1	Reconfigurable Notch Filter Using SMV 1232-011LF	244
4.14.2	Reconfigurable Notch Filter Using SMV 1413-079LF	250
4.14.3	Reconfigurable UWB Antenna with Notch Filter Using SMV 1232-011LF	255
4.14.4	Reconfigurable UWB Antenna with Notch Filter Using SMV 1413-079LF	259
4.15	Comparison of Results	265
4.16	Summary	267

<b>5.</b>	<b>CONCLUSION AND FUTURE WORKS</b>	<b>268</b>
5.1	Conclusion	268
5.2	Future Work	270
<b>REFERENCES</b>		<b>272</b>
<b>APPENDICES</b>		<b>299</b>

## LIST OF TABLES

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Comparison of different tunable device technologies (Lourandakis et. al., 2012)	20
2.2	Summary of reconfigurable microstrip filters of several researchers	57
2.3	Summary of reconfigurable microstrip antenna of several researchers	65
2.4	Comparison all the bands in percentage	71
2.5	Summary of UWB antenna with band-notched of several researchers	82
2.6	Summary of reconfigurable UWB antenna with band-notched of several researchers	90
3.1	SIW filter specification	97
3.2	FR-4 substrate properties	99
3.3	Bandstop filter (notch filter) specification	101
3.4	Roger Duroid 4350B substrate properties	102
3.5	Microstrip patch antenna specification	103
3.6	UWB antenna specification	109
3.7	Single-mode integrated filter and antenna specification	111
3.8	UWB antenna with band-notched specification	113
4.1	Impedance scaling network element values for single-mode bandpass filter	124

4.2	FR-4 substrate properties	126
4.3	Geometric dimensions of single-mode rectangular SIW bandpass filter	129
4.4	Impedance scaling network element values for single-mode bandpass antenna	132
4.5	Geometric dimensions of single-mode rectangular microstrip patch antenna	137
4.6	Impedance scaling network element values for integrated filter and antenna	142
4.7	Geometric dimensions of the multilayer structure	148
4.8	Geometric dimensions of single-mode reconfigurable rectangular SIW bandpass filter	157
4.9	Geometric dimensions of single-mode reconfigurable rectangular microstrip patch antenna	166
4.10	Geometric dimensions of the reconfigurable multilayer structure	181
4.11	Comparison results with previous works	198
4.12	Impedance scaling network element values for UWB antenna	199
4.13	Roger Duroid 4350B substrate properties	201
4.14	Geometric dimensions of UWB circular patch antenna	203
4.15	Impedance scaling network element values for notch filter	209
4.16	Geometric dimensions of notch filter	214
4.17	Geometric dimensions of reconfigurable L-shaped notch filter	223
4.18	Geometric dimensions of the UWB antenna with notch filter	233
4.19	Geometric dimensions of reconfigurable UWB antenna with notch filter	240

4.20	Geometric dimensions of reconfigurable L-shaped notch filter	248
4.21	Geometric dimensions of reconfigurable L-shaped notch filter	253
4.22	Geometric dimensions of reconfigurable UWB antenna with notch filter	258
4.23	Geometric dimensions of reconfigurable UWB antenna with notch filter	262
4.24	Comparison among the design using different types of varactor diode (Simulation)	264
4.25	Comparison results with previous works based on UWB antenna with notch filter	265
4.26	Comparison results with previous works based on reconfigurable UWB antenna with band-notched	266

## LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Typical block diagram of receiving front end of a communication system	2
1.2	Typical block diagram of the RF front end of wireless communication systems in the base station (Hunter, 2001)	3
1.3	UWB spectrum with various bands for radio frequency communication systems (Oppermann et. al., 2005)	5
2.1	Inductor with finite resistance	15
2.2	Circuit representations of resonators with finite resistances	16
2.3	Insertion loss as function as function of difference $Q_u$ values (Hunter, 2001)	16
2.4	An example of fabricated tunable bandstop filter (Xiang et. al., 2014)	19
2.5	Lowpass prototype of single-mode filter	20
2.6	Equivalent circuit of single-mode bandpass filter	21
2.7	Equivalent circuit of single-mode bandpass filter with varactor diode	22
2.8	Lowpass prototype of filter	23
2.9	Equivalent circuit of bandstop filter	23
2.10	Equivalent circuit of bandstop filter with varactor diode	24
2.11	Lowpass prototype (a) single-mode antenna (b) higher mode antenna	25



2.12	Equivalent circuit (a) single-mode antenna (b) higher mode antenna	25
2.13	Equivalent circuit of single-mode antenna with varactor diode	26
2.14	Lowpass prototype equivalent circuit of integrated second order filter and antenna	27
2.15	Equivalent circuit of integrated second order filter and antenna	27
2.16	Equivalent circuit of integrated second order filter/antenna with varactor diode	28
2.17	The electromagnetic spectrum (Pozar, 2005)	29
2.18	SIW topology (Deslandes and Wu, 2003)	31
2.19	The triangular cavities structure (Qiu et. al., 2015)	32
2.20	(a) Proposed filter design (b) Simulated and measured response of the proposed filter design (Kong et. al., 2016)	33
2.21	(a) Sixteenth-mode filter (b) Simulated E-field distributions with fictitious magnetic walls of full-mode SIW (Azad and Mohan, 2017)	33
2.22	(a) Dual mode SIW filter with perturbation vias (b) Simulated and measured response (Cheng et. al., 2015)	34
2.23	(a) SIW bandpass filter with U-shaped slot (b) Simulated and measured response (Chen et. al., 2015)	34
2.24	Waveguide shaped (a) circular (b) rectangular	36
2.25	Proximity-coupled patch antenna (a) top view (b) bottom view (Bakariya et. al., 2014)	38
2.26	Simulated and measured (a) return loss (b) peak gain of the proposed antenna (Liang et. al., 2016)	39

2.27	(a) Fabricated centre-fed dual-band monopolar antenna (b) Comparison between simulated and measured return loss (c) Simulated and measured gain (Dai et. al., 2016)	40
2.28	Proposed $\pi$ -shaped slotted antenna (Sharma et. al., 2015)	41
2.29	Layout structure of the multilayer, multi-technology slotline dipole/Chebyshev filter (Nadan et. al., 1998)	43
2.30	Configuration of the proposed filtering antenna (Zulkifli et. al., 2015)	44
2.31	Fabricated 2 x 2 integrated filter-antenna array (Sahoo et. al., 2017)	44
2.32	Fabricated edge coupled filter-antenna (a) top view (b) bottom view (Kang et. al., 2016)	45
2.33	Proposed structure an integrated filter and antenna (Yusuf et. al., 2013)	46
2.34	(a) 3-D model of the proposed integrated filter and antenna (b) Comparison simulated and measured response (Jiang et. al., 2015)	46
2.35	SIW filter-antenna module's topology (Nova et. al., 2011)	47
2.36	Bottom and top view of fabricated filter-antenna (Wu et. al., 2013)	48
2.37	(a) Measured return loss for tunable centre frequency (b) Fabricated four-pole bandpass-to-bandstop filter (Cho and Rebeiz, 2014)	49
2.38	Fabricated reconfigurable S-shaped split ring resonator (Horestani et. al., 2016)	50
2.39	(a) Fabricated tunable power divider (b) Measured results of the proposed design at 0.8 V and (c) at 4.5 V (Shen et. al., 2015)	51
2.40	(a) Fabricated UWB filter (b) Simulated and measured results of fabricated UWB filter (Zhu and Chu, 2013)	52

2.41	Frequency response of the four-pole combline filter (Martin et. al., 2012)	52
2.42	Simulated and measured (a) S21 (b) S11 data of the tunable CPW-LPF (Huang et. al., 2013)	53
2.43	Experimental results of the varactor-tune bandpass filter Luo et. al., 2014)	54
2.44	Proposed tunable HMSIW bandpass filter with biasing circuit (Tian et. al., 2016)	55
2.45	Simulated and measured results based on bandwidth tuning (Guyette, 2012)	56
2.46	Measured return loss in different tuning states (Del-Barrio et. al., 2015)	58
2.47	Simulated reconfigurable inverted-F antenna model 1 – ground plane, 2 – high frequency branch, 3 – low frequency branch, 4 – port, 5 – matching LC circuit, 6 – varactor diode, 7 – FR-4 substrate, 8 – decoupling LC circuit (Grigoriev and Djalilov, 2016)	59
2.48	Fabricated reconfigurable single feed dual band antenna (a) top view (b) bottom view (Damman et. al., 2016)	60
2.49	Measured results characteristics of the proposed antenna (a) V1 varied (V2 = 0 V) (b) V2 varied (V1 = 0 V) (Ikeda et. al., 2016)	60
2.50	Simulated and measured return loss of the proposed design (Sun et. al., 2013)	61
2.51	Fabricated reconfigurable antenna (Chen et. al., 2017)	62

2.52	Fabricated reconfigurable antenna corresponding to U-NII band (a) top view (b) bottom view (Mansoul et. al. 2014a)	63
2.53	Fabricated bottom view of the reconfigurable antenna (Mansoul et. al., 2014b)	64
2.54	Proposed reconfigurable antenna (Qin et. al., 2015)	66
2.55	Reconfigurable filtenna configuration (Ramadan et. al., 2015)	67
2.56	Proposed reconfigurable filter and antenna (Atallah et. al., 2016a)	67
2.57	The proposed reconfigurable filtenna (a) T-shaped (b) H-shaped (Atallah et. al., 2016b)	68
2.58	Dimension and configuration of the proposed design (a) balun BPF (b) bowtie antenna with balun BPF (Liao and Chen, 2016)	69
2.59	Basic concept of UWB antenna with band-notched (a) UWB antenna with bandpass response (b) bandstop filter with notch response (c) UWB antenna with band-notched with response	72
2.60	Fabricated dual trident UWB antenna with band-notched response (Gorla and Harackiewicz, 2015)	74
2.61	The simulated and measured results of the UWB antenna with fabricated design (Ibrahim and Abdalla, 2016)	75
2.62	Fabricated UWB antenna with dual band-notched (a) top view (b) bottom view (Singh et. al., 2016)	76
2.63	Measured result for UWB CPW for Ant.2 Ant.3 (circular CSRR) design (Yem et. al., 2015)	77
2.64	Fabricated UWB antenna design (Azim et. al., 2014)	77

2.65	Fabricated UWB antenna with two I-shaped with two rotated 90 degree S-shaped (Rathore et. al. ,2014)	78
2.66	Fabricated UWB antenna with L-shaped slot and rectangular slit (from left: ground plane and top plane) (Zhang and Li, 2015)	79
2.67	Fabricated UWB antenna by Saxena and Gangwar (2016)	79
2.68	Fabricated dual band-notched antenna design (a) top view (b) bottom view (Abdalla et. al., 2016)	80
2.69	Simulated response of the UWB antenna design with dual band-notched (Sharma and Park, 2016)	81
2.70	(a) Proposed UWB antenna with varactor diodes (b) Effect of varactor diode capacitance, $C_1$ on return loss (S11) response (c) Effect of varactor diode capacitance, $C_2$ on return loss (S11) response (Li et. al., 2016)	83
2.71	Fabricated reconfigurable UWB antenna (From left: Patch view and ground view) (Chen and Chu, 2015)	84
2.72	Fabricated reconfigurable UWB antenna using interdigital capacitance loading loop resonators (Li et. al., 2016)	85
2.73	Fabricated reconfigurable UWB antenna (a) top view (b) bottom view (c) simulated and measured response of the UWB antenna design Atallah et. al. (2016)	86
2.74	(a) Fabricated reconfigurable UWB antenna using MEMS (b) Comparison between simulated and measured with MEMS 'OFF' (c) Comparison between simulated and measured with MEMS 'ON' with zoom detail on the WLAN region (Anagnostou et. al., 2014)	87

2.75	Fabricated reconfigurable UWB antenna (a) top view (b) bottom view (c) Comparison between simulated and measured response (Tasouji et. al., 2013)	88
2.76	Fabricated reconfigurable UWB antenna with bias network (Horestani et. al., 2016)	89
2.77	Comparison between simulated and measured of the reconfigurable UWB antenna for both the switches condition (Jacob et. al., 2014)	89
3.1	Flow chart of the research	96
3.2	Rectangular waveguide resonator	98
3.3	SIW filter (top view)	100
3.4	Circuit representation of a single-mode SIW filter	100
3.5	Circuit representation of a notch filter	102
3.6	Transmission line model	104
3.7	E-fields distribution for mode $t = 1$	105
3.8	Microstrip patch antenna	108
3.9	Circuit representation of a single-mode antenna	109
3.10	Circuit representation of a UWB antenna	110
3.11	Circuit representation of single-mode integrated SIW filter and patch antenna	112
3.12	RF biasing circuit	114
3.13	(a) Reconfigurable SIW filter view of the multilayer structure (b) reconfigurable microstrip patch antenna view of the multilayer structure	115
3.14	Reconfigurable notch filter with biasing components	116

3.15	CST MWS software environment	118
3.16	The proposed design is hold using the crocodile clips during the soldering process	119
3.17	(a) Radiation pattern measurement setup (b) gain measurement setup	121
4.1	Simulated response of lowpass prototypes (single-mode)	123
4.2	(a) Equivalent circuit of single-mode bandpass filter (b) Simulated response of first order Chebyshev bandpass (single-mode)	124
4.3	Single-mode rectangular SIW bandpass filter	127
4.4	Effect of $l_1$ of single-mode rectangular SIW bandpass filter	128
4.5	Magnitude of E-field of single-mode rectangular SIW bandpass filter	129
4.6	Simulated result of single-mode rectangular SIW bandpass filter	129
4.7	Manufacturing single-mode rectangular SIW bandpass filter	130
4.8	Measured results of single-mode rectangular SIW bandpass filter	131
4.9	Comparison between simulated and measured response	131
4.10	Simulated response of lowpass prototypes (single-mode)	132
4.11	(a) Equivalent circuit of single-mode antenna (b) Simulated response of first order antenna (single-mode)	133
4.12	Single-mode rectangular microstrip patch antenna	136
4.13	Effect of $L_a$ of single-mode rectangular microstrip patch antenna	137
4.14	Magnitude of E-field of single-mode rectangular microstrip patch antenna	138
4.15	Simulated results of rectangular microstrip patch antenna	138
4.16	Simulated radiation pattern	139
4.17	Manufacturing single-mode rectangular microstrip patch antenna	140

4.18	Measured results of rectangular single-mode microstrip patch antenna	140
4.19	Comparison between the simulated and measured response	141
4.20	Comparison of simulated and measured results for radiation pattern	141
4.21	Simulated response of lowpass prototype (single-mode)	142
4.22	(a) Equivalent circuit of integrated second order filter and antenna (b) Simulated response of single-mode integrated bandpass filter and antenna	143
4.23	(a) SIW filter view of the multilayer structure (b) microstrip patch antenna view of the multilayer structure (c) ground plane view with the T-shaped slot (d) side view of the multilayer structure	146
4.24	Circuit representation of single-mode integrated SIW filter and patch antenna	147
4.25	Effect of $h_5$ of the multilayer structure	147
4.26	Magnitude of E-field for multilayer structure (a) SIW filter view (b) patch view at centre frequency of 1.998 GHz	149
4.27	Simulated results of the multilayer structure	149
4.28	Simulated radiation pattern	150
4.29	Manufacturing integrated SIW filter and patch antenna (from left: patch antenna and SIW filter)	151
4.30	Manufacturing integrated SIW filter and patch antenna (ground plane)	152
4.31	Measured results of the multilayer structure	152
4.32	Comparison between the simulated and measured response	153
4.33	Comparison of simulated and measured for radiation pattern	153